MULTI-BEAM OPTICAL SCANNING DEVICE

FIELD OF THE INVENTION

The present invention relates to a multi-beam optical scanning device for writing on
and/or reading out from an information carrier.

The present invention also relates to a method for writing on and/or reading out from
an information carrier using such an optical scanning device.

The present invention is particularly relevant for multi-dimensional data storage on
optical discs.

BACKGROUND OF THE INVENTION

An optical disc is made of a transparent substrate in which data, in the form of a serial
bitstream, are encoded as a series of marks in a reflective surface within the disc. The marks
are arranged along a spiral track. Data are read from the optical disc by an optical scanning
device, comprising a laser beam which is focused onto a track on the disc by focusing means
and detecting means for detecting the light reflected from the surface of the disc. By rotating
the optical disc, the light reflected from the surface of the disc is modulated by the pattern of
the pits rotating into and out the field of laser illumination. The optical scanning device
detects the modulated reflected laser light and produces an electrical signal that is decoded to
recover the digital data stored on the optical disc. The optical scanning device comprises a
pickup assembly that may be positioned and focused to read or write data on any disc track
despite disk warpage or eccentricity.

To this end, the optical scanning device usually comprises a servo mechanism
comprising focus error detecting means, which measure certain parameters of a light spot
formed by the illumination beam reflected from the optical disc onto a detector, and an
actuator for moving the focusing means in order to keep the optical disc in focus. The focus
error detecting means use several conventional methods like for instance the astigmatic or the
Foucault methods.

Multi-beam optical scanning devices are now being developed, which allow data
retrieval of conventional discs and which additionally allow reading optical discs having
multiple concentric spiral or circular tracks. Such multi-beam optical scanning devices cause
difficulties for focus error detection and correction, because the multiple beams are very
close to each other, which places severe constraints on the size of the detector. If the detector
is too large, several spots impinge in the detector. The large diameter of the spots may also

cause crosstalk between neigbouring beams. Additionally, when out of focus, the spots may extend beyond the detector or overlap with each other, thus making it difficult to obtain an accurate focus error signal.

5   US patent 6,229,771 discloses focus error detection means for use in a multi-beam optical scanning device. The disclosed focus error detection means, which implement the astigmatic method, comprise an optical element, either a holographic element or a diffractive grating, that generates a separate set of beams for use in determining the focus error. These beams are directed onto multi-element focus detectors configured to account for overlap between spots. The design of the focus detector, in conjunction with rotation of an axis for

10   astigmatism and a spacing of the spots onto the detector by the optical elements permits generation of a focus error signal that compensates for the spot size exceeding the size of the detector and overlap between the spots.

A drawback of this solution is that it does not avoid a formation of overlapping spots onto the detector. Furthermore, it is not adapted to optical scanning devices with focus error

15   detecting means implementing the Foucault method.

SUMMARY OF THE INVENTION

The object of the invention is to propose a solution for avoiding interference and

20   overlapping of a plurality of spots when processed by focus error detection means implementing the Foucault method.

This is achieved by an optical scanning device comprising:

- a radiation source for producing a radiation beam,
- means for dividing the radiation beam into a plurality of radiation sub-beams,

25   - focusing means for focusing the plurality of radiation sub-beams on an information carrier intended to reflect said plurality of radiation sub-beams towards a detection branch,

- focus error detection means, comprising on said detection branch, a servo lens for focusing said plurality of reflected radiation sub-beams onto a focus plane, a spatial filter

30   for isolating a reflected radiation sub-beam from said plurality of reflected radiation sub-beams at the focus plane and a detector for detecting a focus error signal from said isolated reflected radiation sub-beam.

At the focus plane, the plurality of reflected radiation sub-beams is expected to be focused or close to focus. The spatial filter in accordance with the invention is intended to block all the radiation sub-means but one. Therefore, only one radiation spot is detected by the detector, which is able to measure an accurate focus error signal. Consequently, with the

5   invention, a valuable S-curve can be obtained from which an error signal giving the amount of defocus is derived.

Advantageously, the optical scanning device comprises decision means for deciding of a type of focus error correction depending of said detected focus error signal.

10   When the radiation spots are close to focus, the spatial filter is efficient at masking all the radiation sub-beams but one. However, when the reflected radiation sub-beams are too far away from focus, several reflected radiation sub-beams may interfere at the spatial filter plane, partly pass through the spatial filter and form overlapping radiation spots at the detector. In this case, the detector detects several overlapping radiation spots. The obtained

15   focus error signal therefore comprises contributions from several radiation spots and cannot lead to a valuable S-curve.

The decision means in accordance with the invention determine a capture range, within which the detected focus error signal contributes to a valuable S-curve. When the detected focus error signal is within the capture range, a position error is calculated from the

20   S-curve and used for correcting a position of the focusing means. A closed loop correction is achieved. On the contrary, when the detected focus error signal goes out of this capture range, no position error is calculated from the S-curve and the focusing means position is changed by a predetermined displacement unit. An open loop correction is achieved until the detected focus error signal goes within the capture range.

25   An advantage of the invention is to adapt the type of correction to the amount of defocus.

In a first embodiment of the invention, the spatial filter comprises a slit. The slit,

30   which blocks the light in one dimension, is well adapted to a one dimensional array of spots. An advantage of a slit is that the alignment along one axis is non-critical.

In a second embodiment of the invention, the spatial filter comprises a hole. A hole, which blocks the light in two dimensions, is well adapted to the use of a two-dimensional array of read-out spots.

These and other aspects of the invention will be apparent from and will be elucidated
5   with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described in more detail, by way of example, with reference to the accompanying drawings, wherein:

10   -   Fig. 1a is a schematical drawing of an optical disc comprising multiple concentric spiral data tracks,

-    Fig. 1b is a schematical drawing of the layout of the data on a 2D track,

-    Fig. 2 is a schematical drawing showing the light path in the optical scanning device for multiple beam reading,

15   -   Figs. 3a, 3b and 3c illustrate the principles of the knife edge Foucault method,

-    Fig. 4a shows an S-curve obtained from the focus error signal,

-    Figs. 4b and 4c illustrate the light path in the detection branch in accordance with the invention, with two possible positions of the focus plane,

-    Fig. 5 is a schematical drawing showing the light path in an optical scanning device in
20   accordance with the invention,

-    Figs. 6a and 6b show a schematical drawing of the detector in accordance with an embodiment of the invention,

-    Figs. 7a and 7b show S-curves obtained without and with the invention.

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30   **DETAILED DESCRIPTION OF THE INVENTION**

In the following, the invention will be described for an optical disc allowing a two-dimensional data storage. It should be noted however that the invention more generally concerns applications using closely spaced, but distinct focused beams, for which a focus error signal has to be derived. This can be multi-beam access to optical storage information

carriers, such as conventional formats like Compact Discs (CD), Digital Versatile Disks (DVD), Blu-ray discs (BD), two-dimensional or higher dimensional formats. This can also concern surface patterning applications outside of data storage, such as optical writing on a surface, surface cleaning, optical tweezer concepts.

5   Fig. 1a is a schematical drawing of an optical disc comprising multiple concentric spiral tracks forming a broad spiral track BS. As shown in Fig. 1b, the broad spiral track BS has a 2D storage capacity with a plurality of contiguous linear data tracks. The broad spiral track is read by an optical scanning device, which divides a radiation beam into as many sub-beams as there are linear data tracks in the broad spiral BS.

10   Fig. 2 describes in a schematical way an optical scanning device for reading the optical disc of Fig. 1a. The optical scanning device comprises a radiation source 1 for producing a radiation beam RB, a grating 2 for dividing the radiation beam RB into a plurality of radiation sub-beams RSB_1 to RSB_N, where N is an integer, focusing means for focusing the radiation sub-beams RSB_1 to RSB_N on the optical disc OD along an optical path.

15   The focusing means in particular comprise a collimator lens 3 and an objective lens 4. The radiation sub-beams RSB_1 to RSB_N are reflected by the optical disc OD and redirected towards a focus detection branch by a beam splitter 5. Said focus detection branch comprises focus error detection means, which implement the Foucault method of detecting a focus error signal. The focus error detection means comprise a servo lens 6 for focusing the reflected

20   radiation sub-beams onto a focus plane FP, splitting means 7 for splitting the reflected radiation sub-beams into two halves and a split detector 8 for detecting spots formed by the two halves of the reflected radiation sub-beams. The split detector calculates a focus error signal FES from the detected light spots and draws an S-curve of the focus error signal as a function of a displacement of the objective lens 4. The optical scanning device further

25   comprises correction means 9, which comprise servo electronics for driving an actuator 10, said actuator actuating the objective lens 4 so as to correct a focus error. The focus error detection means and the correction means usually form a closed servo loop, in which the position of the objective lens 4 is changed in order to make the focus error signal value as close as possible to zero.

30   The optical scanning device further comprises a high frequency detection branch for retrieving the data read on the optical disc OD. The reflected sub-beams RSB_1 to RSB_N are redirected onto the high frequency detection branch by a beam splitter 30 and focussed by a second servo lens 31 onto a high-frequency detector 32, where they form read-out spots. The high-frequency detector measures the read-out spots separately.

It should be noted that this detection branch is usually integrated with the focus detection branch by using a grating or an holographic element similar to the splitting means 7.

Figs 3a to 3c illustrate the principles of the Foucault method. The splitting means 7 are for instance a knife edge, but they can be a wedge, a split grating or a split hologram as well. The Foucault method is based on the principle that a longitudinal shift of the focus point gives rise to a displacement of the radiation beam center of mass at the split detector 8. The servo lens 6 images the focal point of the radiation beam at the splitting means 7. When the disc is not in focus the distance traveled by the radiation beam of the radiation source is longer and the focal point of the beam is either before or after the splitting means 7. Fig. 3a shows a radiation beam which is in focus, Fig. 3b a radiation beam, which focuses after the focus plane and Fig. 3c a radiation beam which focuses before the focus plane.

As shown in Fig. 3a, when the radiation beam is focused, two symmetrical halves of a spot are formed on detection areas D_1 and D_2 of the split detector 8. As shown in Figs. 1b and 1c, when the radiation beam is defocused, the halves of the spot are no more symmetrical.

Fig. 4a presents an S-curve obtained from the spots formed on the split detector. A signal S_1 and a signal S_2 received on the detection areas D_1 and D_2 of the split detector are measured. They contribute to the focus error signal FES in the following way:

$$FES = \frac{S1 - S2}{S1 + S2}$$

The focus error signal obtained is used to draw a S-curve, as a function of a displacement z of the objective lens 3.

The zero point of the S-curve corresponds to the in-focus position.

Figs. 4b and 4c present focus error detection means in accordance with the invention. Said focus error detection means comprise a spatial filter 20, which is placed at the focus plane FP in order to filter the radiation sub-beams and only let pass one radiation sub-beam.

Advantageously, the spatial filter has a diameter which is equal to the separation of the spots at the focus of the servo lens. In this way, the spatial filter is just large enough to transmit one spot and is just small enough to block the other spots in order to have maximal S-curve length.

The Foucault method can be implemented in two ways: the servo lens 6 can focus the reflected radiation sub-beams either onto the splitting means as shown in Fig. 4b, or onto the split detector as shown by Fig. 4c. In the first case, the spatial filter 20 in accordance with the

invention is placed just before the splitting means. In this case, it should be noted that the spatial filter could be implemented by manufacturing the part of the wedge corresponding to the transmissive area of the spatial filter with a transmissive material and to embed this part into a non-transmissive holder. An advantage of such an alternative is to get rid of any

5   problem of placement of the spatial filter with respect to the wedge.

In the second case, the spatial filter 21 in accordance with the invention is placed just before the split detector. The spatial filter function can also be integrated into the detector by limiting the size of the detection element accordingly.

Advantageously, the spatial filter 20 has a diameter which is equal to the separation of

10   the radiation sub-beams at the focus of the servo lens. For the optical disc presented in Figs. 1a and 1b, the separation of the radiation sub-beams is equal to 2.8 λ/NA, where λ stands for a wavelength and NA for a numerical aperture of the radiation sub-beams.

In this way, the spatial filter is just large enough to transmit one radiation sub-beam and is just small enough to block the other radiation sub-beams. Therefore, at the split

15   detector 8, only one spot is formed, which allows calculating an accurate focus error signal and drawing an S-curve with maximal S-curve length. It is to be noted that the S-curve length corresponds to a range of positions of the objective lens 4, for which the read-out spots are out-of-focus but still yield a correct position error signal.

In a first embodiment of the invention, the spatial filter comprises a slit. The slit,

20   which blocks the light in one dimension, is well adapted to a one dimensional array of spots. An advantage of a slit is that its alignment is noncritical in one dimension.

In a second embodiment of the invention, the spatial filter comprises a hole. A hole, which blocks the light in two dimensions, is well adapted to two-dimensional array of spots.

25   Advantageously, as shown in Fig. 5, the focus error detection means in accordance with the invention further comprise decision means 11 for deciding of a type of focus error correction depending of said detected focus error signal. As a matter of fact, when the radiation sub-beams are close to focus, the spatial filter is efficient at masking all the reflected radiation sub-beams but one. Therefore, the S-curve is reliable and can be validly

30   used for driving the lens actuator 10. However, when the radiation sub-beams are too far away from focus, several radiation sub-beams may interfere at the spatial filter plane, partly pass through the spatial filter and form overlapping radiation spots at the split detector 8. In this case, the split detector 8 detects several overlapping radiation spots. The obtained focus error signal therefore comprises contributions from several radiation spots and cannot lead to

a valuable S-curve. To prevent the closed servo loop from correcting the objective lens position on a wrong basis, the decision means in accordance with the invention decide when the focus error signal FES can be validly used for correcting the objective lens position. To this end, the decision means 11 advantageously calculate a central aperture (CA) signal from the signals S_1 and S_2 measured on the detection areas D_1 and D_2 respectively, in the following way: CA = S1 + S2. The decision means then decide to use the focus error signal FES to correct the objective lens position if the CA signal is included into a capture range.

Advantageously, the decision means 11 decide that the focus error signal FES can be validly used if the CA signal is higher than a first predetermined threshold. As a matter of fact, strongly defocused radiation sub-beams form overlapping spots on the two halves of the split detector, which lead to a far lower CA signal than when the radiation sub-beams are close to focus.

It should be noted that the threshold value depends on the application.

When the CA signal is below the first predetermined threshold, the decision means 11 decide that the objective lens position cannot be efficiently corrected on the basis of the S-curve and an open loop correction is achieved: for instance, the actuator 10 moves the objective lens 3 of a predetermined step. A new measure of the CA signal is performed by the focus error detection means. If the CA signal increases, this means that the displacement has been applied in the right direction. The operation is repeated until the decision means can decide to re activate the closed servo loop, that is when the CA signal is within the capture range.

In an alternative of the invention presented in Figs. 6a and 6b, the split detector 8 comprises two additional detection halves D_3 and D_4, forming with the two detection halves D_1 and D_2 an extended detection area EDA for detecting an intensity of a spot extending beyond the detection areas D_1 and D_2. Fig. 6a shows a spot which is included within the two halves D_1 and D_2 of the detector. On the contrary, Fig. 6b shows a spot whose diameter is larger than the two halves D_1 and D_2 and which covers the two additional halves D_3 and D_4. With said alternative of the invention, a first measure of a first CA signal is performed in the two halves D_1 and D_2 and a second measure of a second CA signal is performed in the additional halves D_3 and D_4. A focus error signal is derived from the first measure. A normalised CA signal CA_N is calculated as a ratio of the signals measured on the two halves D_1 and D_2 and on the two additional halves D_3 and D_4 in the following way:

$$CA_N = \frac{S_1 + S_2}{S_3 + S_4}$$

The decision means decide to use the focus error signal for correcting the objective lens position if said normalised CA signal CA_N is higher than a second predetermined threshold. An advantage of said alternative is to measure how far the spot formed by the isolated reflected sub-beam goes beyond the detection areas D_1 and D_2 of the detector 8. This measure is taken into account in the decision. Therefore, with said alternative of the invention, the focus error signal is exploited for not too large spots with a high enough intensity.

Fig. 7a shows an experimental focus error signal FES_1 and a square wave signal SWS_1 obtained from an optical scanning device comprising a plurality of radiation sub-beams for reading out a 2D concentric spiral track as shown in Fig. 1b. The square wave signal SWS_1 is derived from the CA signal of the split detector. Multiple S-curves are visible and there is a large offset, so that the S-curves do not cross the zero voltage line.

Fig. 7b shows a CA signal CAS, a square wave signal SWS_2 and an experimental focus error signal FES_2 obtained from an optical scanning device comprising a plurality of radiation sub-beams for reading out a 2D concentric spiral track in accordance with the invention. The square wave signal SWS_2 is derived from the CA signal CAS of the split detector and indicates the threshold TH used. When the CA signal is above the threshold, the focus error signal FES_2 shows a pronounced focus S-curve .

The drawings and their description hereinbefore illustrate rather than limit the invention. It will be evident that there are numerous alternatives, which fall within the scope of the appended claims. In this respect the following closing remarks are made: there are numerous ways of implementing functions by means of items of hardware or software, or both. In this respect, the drawings are very diagrammatic, each representing only one possible embodiment of the invention. Thus, although a drawing shows different functions as different blocks, this by no means excludes that a single item of hardware or software carries out several functions, nor does it exclude that a single function is carried out by an assembly of items of hardware or software, or both.

Any reference sign in a claim should not be construed as limiting the claim. Use of the verb "to comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. Use of the article "a" or "an" preceding an element or step does not exclude the presence of a plurality of such elements or steps.